A Proposed Synopsis

On the topic

"USES OF GROUND BASED ALL SKY IMAGER FOR THE INVESTIGATION OF MIDDLE AND UPPER ATMOSPHERIC PHENOMENA"

SWAMI RAMANAND TEERTH MARATHWADA UNIVERSITY, NANDED

For the Registration of

Doctor of Philosophy in Physics

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2021-2022

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Title of Research Proposal:

USES OF GROUND BASED ALL SKY IMAGER FOR THE INVESTIGATION OF MIDDLE AND UPPER ATMOSPHERIC PHENOMENA

Introduction :

The Earth's atmosphere can be divided into different layers according to different parameters such as temperature, pressure, density, etc. Temperature is one of the main property on which other atmospheric parameters depend. Therefore, on the basis of temperature change, the atmosphere can be divided into four major layers named as troposphere (0-12 km), stratosphere (12-60 km), mesosphere (60-90 km) and thermosphere (90-1000 km). Small intermediate layers that serve as transition from one layer to the next are tropopause (lies between top of troposphere and bottom of stratosphere), stratopause (lies between top of stratosphere and bottom of mesosphere) and mesopause (lies between top of mesosphere and bottom of thermosphere) [1].

Due to solar energy, above 60 km, various atoms and moleculs become ionized. In 1924, first time, radio scientist Edward V. Appleton and M. A. F. Barnett introduced the word 'ionosphere'. They showed that the signal received at a distance was indeed a reflection of transmitted wave, high in the atmosphere. This reflecting region, at a height about 200 km to 400 km, was at one time known as the Appleton layer. The maximum concentration of ions occurrs in between an altitude of about 200 km to 450 km and range of altitude varies with geomagnetic activity.

The ionosphere is biggest natural laboratory to study the variety of photo-chemical reactions and to investigate the fundamental physics. This region is sub-categorized into D, E and F –region, and, is very important for communication and navigation. Therefore, it is very important to understand the dynamics of ionosphere and its driving forces. In the F region at low latitude, plasma irregularities have been frequently observed due to the instability processes occurring in the ionized medium. Dark patches in optical data are observed due to low electron density as compared to the background density of the ionosphere, these dark patches are the manifestation of plasma irregularities and are known as "Equatorial Plasma Bubbles (EPBs)". These EPBs are generated on the bottom side of F region. When radio waves pass through EPBs, they get disturbed and an error occurs in communications [2]. The understanding of the EPBs

and its growth mechanism is one of the most challenging issue in the dynamics of the equatorial F region. So, it is of scientific interest to study the occurrence, morphology, generation of EPBs and their dynamics.

Another atmospheric phenomena are gravity waves. Gravity waves are observed time periods in the range of few minutes to about an hours. These are originated in lower atmosphere due to various atmospheric disturbances and attain multi-folded amplitude by the time they reach in the upper atmosphere. Usually, these types of waves are well captured in the mesospheric nightglow emissions using imaging technique. Such waves have short horizontal wavelengths and long vertical wavelengths. The waves with vertical wavelengths typically above 10 km passing through the airglow emission layer would be strong enough to perturb the column integrated airglow emissions and get manifested themselves in the all-sky airglow images. Both the freely propagating and ducted (or evanescent) gravity wave modes perturb the airglow emissions and this makes all-sky imaging a very valuable tool in the study of such waves.

Many space based observation programs capture Earth data and provide valuable historical products in which are utilized in the climate research. These products include spectral images of the surface reflectance in visible andnear-infrared bands. Studies are making use of the satellite imagery to evaluate land cover, vegetation growth, humaninfluence over land surface, cities expansion, weather and climate change, monitor the environment and natural resources. In spite of the great aid these image provide in monitoring change, about two thirds of the captured surfaces are covered by clouds [3] which negatively impact the work of monitoring applications and evaluating land surface change. Solar energy generation is one application which requires accurate estimates of cloud coverage over specific areas [4]. Clouds are a contaminant and their shadows is also impeding remote sensing applications. Due to this restrictive factor, the necessity of assessing cloud cover became more pressing and techniques were developed to enable classification of images based on cloud coverage percentage[3,4].

An Overview of Relevant Literature

The large-scale perturbations have traditionally been studied using instruments such as Scanning photometers, scintillation recorders, interferometers, ionosonde and more recently using Imager, LIDAR soundings. Airglow emissions are an outcome of chemiluminescence property of ambient atomic molecular species in the middle and the upper atmosphere. The light

from the night sky, termed as “nightglow” [5] have been studied by many researchers. The sophisticated rocket, satellite and ground-based remote sensing instruments have provided detail investigation of the nightglow phenomenon. Based on numerous ground based and in situ studies, it is widely accepted that the nightglow OI 630.0 nm emissions can be generated at low latitude F region (250–300 km). The equatorial ionospheric plasma depletions (EPBs) are generally aligned along geomagnetic field lines and move towards eastward throughout the night [6].

In particular, one of the most enigmatic phenomena over equatorial region is Equatorial spread-F (ESF), which manifest in optical airglow emissions as depleted regions of intensity and are oftentermed as equatorial plasma depletions/bubbles (EPBs). It is generally understood that generalized Rayleigh–Taylor (RT) instability is the cause of ESF occurrence (e.g., Kelley et al., 2011). However, for a fast growth of RT instability a seed is required, origin of which is debatable. Reports suggesting the role of, (a) gravity waves of lower atmospheric origin (e.g., Kelley et al., 1981; Prakash, 1999; Takahashi et al., 2009; Taori et al., 2010, 2011), (b) shear generated vortex (Kudeki et al., 2007), (c) large scale wave structures (e.g., Tsunoda, 2008) and (d) planetary waves (e.g., Abdu et al., 2006; Fagundes et al., 2009; Takahashi et al., 2007) in the formation of ESF/EPBs existin the literature. In the light that the occurrence characteristics of this phenomena exhibit large variations from one day to other, it becomes necessary to assess the role and characteristics of upper mesospheric gravity waves (because of their high transience) and their relation with EPB occurrences.

The waves observed in the mesosphere airglow intensity variations have also been attributed to the upward propagating gravity waves generated in the lower atmospheric regions (e.g Tarasick and Shepherd 1992a, 1992b; Fagundes et al. 1995; Nakamura et al. 1999) principally by deep convective activity of thunder storm (e.g Brown et al. 2004; Hecht et al. 2004; Snively and Pasko 2008; Vadaset al. 2009; Siingh et al.2011, 2012) and orography effects (e.g. Tsuda et al.1989; Eckermann and Preusse1999). In literature, Das et al. (2011) have proposed heating effect during dust storm also to be one of the probable generation mechanisms of gravity wave in the middle atmosphere. The short period waves might have been trapped/ducted by thermal ducts and took several hours to reach the mesopause region. The temperature profile recorded by SABER (Sounding of Atmosphereusing Broadband Emission Radiometry) showed the presence of thermal duct (Fadnavis et al. 2009). Winds critically control

the formation of the duct and hence variations in the wind direction and amplitude may account for sporadic/shortlived observations of the short and the long period waves.

In India, few investigators have been using All Sky Imager (ASI) for OI 630.0 nm emission to study the onset evolution and dynamics of EPBs. The dimensions and the circulation path of the EPBs were first time studied by Mukharjee. et al. [6] and Rajesh et al. [7] respectively using OI 630.0 nm images in Indian sector. Several researchers have reported the day to day variations in the occurrence of EPBs in OI 630.0 nm [8,9]. Used OI557.7 nm and OH emission for charecteristion of wave analysis. Many investigators have carried out observational as well as the theoretical studies on the identification and characterization of gravity wave and tidal signatures with wave periodicities ranging from few minutes to several hours [10-14]. Using Ground-based instrumentation with a large field of view would augment satellite cloud observations (e.g. Seiz et al., 2002; Pfister et al., 2003; Souza-Echer et al., 2006; Smith and Toumi, 2008; Liu et al., 2013). Such augmentation improves vertical distribution of clouds, albeit at the measurement locations. These sky-imaging devices (eg., Whole-sky imager, Total-sky imager, All-sky imager, etc.) are automatized to achieve real time hemispheric sky images and cloud fraction (e.g Long et al., 2006; Yang et al., 2012; Kazantzidis et al., 2012). Among these imagers, the airglow imager is designed primarily for monitoring emissions from the mesosphere andlower thermosphere (MLT) with good spatial and temporal resolutions. The invent of commercial solid state imaging arrays in the 1980s revolutionized airglow imaging observations and in resolving many technical issues in the image processing, such as long-lasting bands, transient short scale ripples, super imposed transversely propagating waves, airglow depletions (e.g Taylor et al., 1995; Batista et al., 2000) and MLTdynamics, such as mesospheric wave signatures and gravity wave seeding of equatorial plasma bubbles[15] . Since, it is an optical device,the measurements are confined only to clear-sky and new moon periods. Nevertheless, its capability to observe clouds on a continuous basis provides an opportunity to derive the Cloud Motion Vector (CMV'S).

Objectives of the Proposed Study:

The main objectives of the proposed research work are listed below-

1. To study the role of various atmospheric wave (gravity waves, tides and Planetary waves) and their relation with ionospheric electrodynamics at low latitudes.
2. Variations in the zonal drift velocity of ionospheric irregularities (EPB).
3. The parameterization of atmospheric wave parameters in terms of horizontal and vertical wavelengths, wave periods, phase velocity and propagation directions.
4. To study the impact of covid induced Lock Down on ground based optical observations.
5. Utilization of Airglow data to study of Cloud intensity variation and cloud coverage area in ASI images over Kolhapur.

Research Methodology:

a) Data Collection:

Regular observations of night airglow emissions, OI 630.0, OI 557 nm and OH Meinel (683.00nm and 692.00 nm) bands have been carried out by using All Sky Imager (ASI) at low latitude station Kolhapur (16.8^{o}N, 74.2^{o}E) .on clear and moonless nights. The images of OI 630.0 nm, 557.7 nm and OH emission provides the time evolution and spatial variations of selected atomic or molecular emissions over a wide area in the sky. The multispectral (OH, OI 630.0 and OI 577.7 nm emissions) ASI have been installed at Shivaji University Campus, Kolhapur under the scientific collaborative program between Shivaji University, Kolhapur (S.U.K.) and Indian Institute of Geomagnetism (I.I.G.), Navi Mumbai, India to measure the nightglow emissions. This system can be operated for 7 nights before and after the new moon night. ASI consists of three interference filters, having central wavelengths of OI 630.0 nm, OI 557.7 nm and OH Meinel bands (720.0 nm – 910.0 nm) having an exposure time of typically 120, 120 and 30 sec respectively. A high resolution (1,024 × 1,024 pixels) Charge Coupled Device (CCD) based ASI has180^{o} field of view (FOV). Figure 1. Shows the all sky imager covers a zenith angle range of about 70 (140^{o} FOV). This corresponds to horizontal distance about nearly 1220 km in diameter at an altitude of 250 km. Before the operation, dark counts are reduced by thermo-electric cooling of CCD to -80^{o}C. The filter wheel and camera shutter are controlled by a computer. The exposure time for various filters is dependent on the compromise among the background

luminosity, interference filter transmission and actual airglow brightness. The detail of experimental setup has been described by Ghodpage et al., 2014.[16]

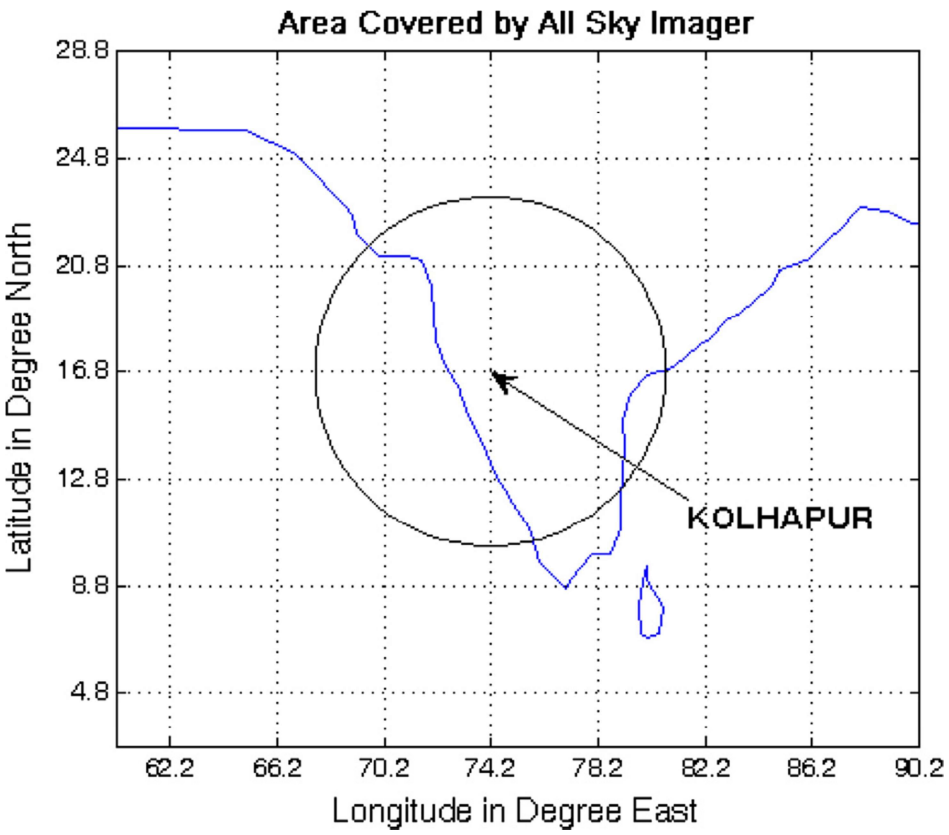

Figure 2. The all sky imager covers a zenith angle range of about 70 (140 FOV). This corresponds to horizontal distance about nearly 1220 km in diameter at an altitude of 250 km.[14].

b) Data Analysis:

Primary we can seen in observed images are Cloud, Pasma bubbles, Gravity wave and background stars. These three types of structuters are observed in ASI images. Sample images of these three are shown in below.

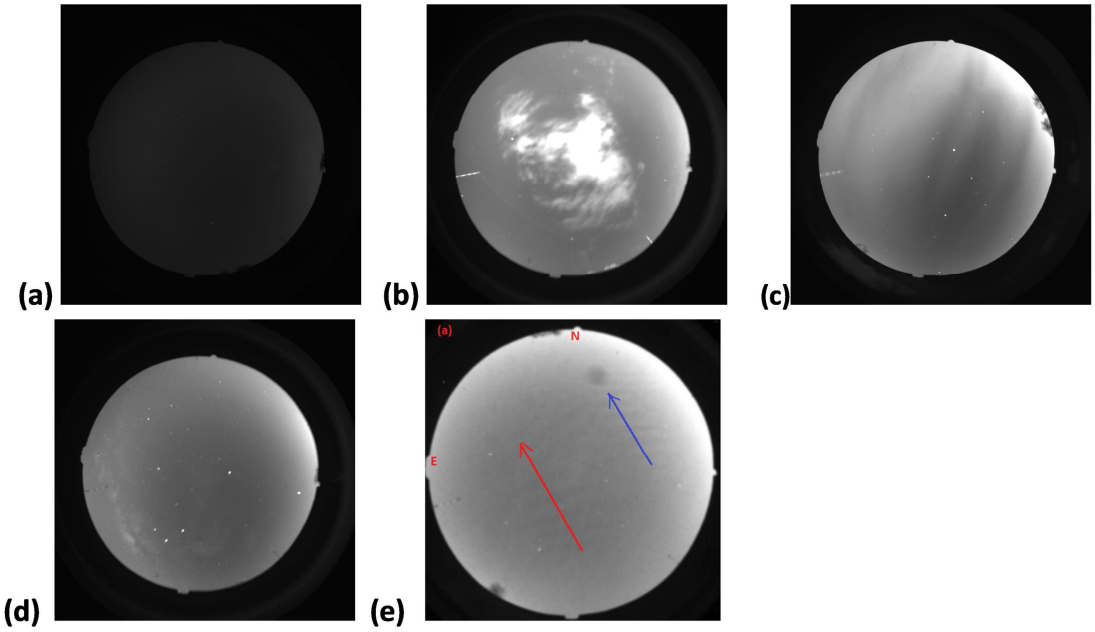

Figure 2. Depicted sample images of ASI (a) Raw iamge (b) Auto adjusted image showing a white patch as a cloud (c) Dark band in figure shown as Equtorial Plasma bubble (EPB) (d) Bright spots are shown as stars in sky (e) Band like structres with red and blue arrow shown as Gravity waves.

The airglow image processing method adopted in our study closely follows the methods elaborated by Garcia et al. (1997) and Kubota et al. (2001). After capturing, the images have to be corrected for (i) actual coordinates, (ii) flat fielding and background brightness and (iii) star brightness. It is important to state here that we have optimized the focus of reimaging lens to achieve best images at mesospheric waves as well as thermospheric depletions. This led us the best images of 558 and 630 nm emissions and poor imaging of short period waves at OH wavelengths (840 nm). The dark patches in the images (EPB) of OI 630.0 nm are the signature of EPBs [5] and usually the EPBs propagate eastward during the nighttime under quiet magnetic conditions [16]. Band like structre in OH and OI 557.7 nm emission are the signature of Gravity Waves[15]. The images are recorded in 1024 * 1024 or 521*512 pixels using ASI at Kolhapur. These pixel numbers can be converted into geographic values (km) by the method described in Garcia et al., [17]. In this method, pixels of nightglow OI 630.0 nm images are converted into

actual geographic values (km) by the following formula based on the geometry of airglow emission layer.

$$\psi = \cos^{-1}\left(\frac{R_h^2 + R^2 - r^2}{2R_h R}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Arc = Radius \times Angle = R_h \times \psi \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where, ψ is earth's centered angle, R is the mean radius of the earth, R_h is the sum of the mean radius of the earth and the height of airglow emission layer, r is the distance between the location of imager and the signature of EPB in the sky, obtained in OI 630.0 nm images. This geometrical method is useful to determine the different parameters of EPBs.The all sky images of nightglow OI 630.0 nm can be analyzed using the different image processing methods described by many researchers [17-20]. Using these image processing methods ionospheric irregularities can be clearly seen in images of nightglow OI 630.0 nm.The geometric method for calculating the parameters and movement of ionospheric irregularities is introduced by Sharma et al.[18]. Pimenta et al. [19] has also described the scanning method to determine the velocity of ionospheric irregularities.

Importance of study/ Society application:

Understanding the daily and seasonal variations in the occurrence of EPBs at a particular location is very important as it causes severe interference and abrupt disruption in trans-ionospheric radio propagation and thus affects the navigation and communication systems. Our study aim to showcase the multiple use cases of ground based optical airglow data varying from cloud study in the lower atmosphere, wave studies in the middle atmosphere to the ionospheric studies in upper atmosphere.

International Status/ National Status:

Many investigators have carried out observational as well as the theoretical studies on the identification and characterization of gravity wave and tidal signatures with wave periodicities ranging from few minutes to several hours (e.g Walterscheid et al., 1987; Hickey, 1988a, b; Reisin and Scheer, 1996; Taori and Taylor, 2006; Guharay et al 2008). Study of the large scale atmospheric waves, Tides and waves, driven in part by the absorption of solar energy at various levels in the atmosphere, play a major role in the dynamics of the mesosphere and lower

thermosphere region (altitude ~80 to 110 km) impacting the wind, temperature and density structure. Recently, there had been several efforts from USA, Brazil, Japanese and Indian researchers to understand these objectives with the help of coordinated multi-station data. Several good papers are published by national/international level. Present study aim to showcase the multiple use cases of ground based optical airglow data varying from cloud study in the lower atmosphere, wave studies in the middle atmosphere to the ionospheric studies in upper atmosphere.

Significance of the study :

The EPBs cause scintillation to the satellite signals which results error in communication and navigation system. Some important parameters like, length, width and zonal drift velocity of EPBs can be determined by OI 630.0 nm emissions. Since the dynamics of EPBs are not well understood, it is very much essential to study the ionospheric irregularities using ground based instrument; All Sky Imager (ASI). The variation in dimensions of EPBs is the key factor in understanding the generation mechanism of EPBs.

The Causative mechanishm of EPB occurrence is linked to the lower atmospheric inputs such as gravity waves, hence, the study of gravity wave characteristics is deemed important. Further, the gravity waves are an outcome of convective processes and orographic structure. Therefore, to resolve one issue we need to know the coupled structure of the atmosphere, which this study aim to perform with the available optical airglow instruments.

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